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## DYNAMICS AND CONTROLS WORKING GROUP SUMMARY

Ronald E. Oglevie, Rockwell International, Chairman

## INTRODUCTION

This working group evaluated the technology status of the dynamics and controls discipline as it applies to energy storage wheel systems. The major conclusion arising from this survey is that no problems were identified for which an adequate solution could not be proposed. In addition to this principal task, the panel undertook to address design issues that influence control. The results of these efforts are presented in this summary report. The membership of the Dynamics and Controls Working Group included 12 persons and is shown in Table 1 at the end of this summary.

## CONCLUSIONS AND RECOMMENDATIONS

The group participants addressed the dynamics and controls aspects associated with not only the energy storage system concept and its various constituent parts, but also the controls task attendant to large, manned spacecraft. The conclusions drawn by this panel along with its recommendations for the enhancement of the appropriate technology are presented herein.

1. Working Group Summary and Sample Opinions

The results of the technology evaluation conducted by this group (Figure 1) indicate that there are no problems in the dynamics and controls area for which an adequate solution cannot be presented. It is clear that in the dynamics of high-speed rotating machinery there are potential pitfalls. However, design experience has shown that early recognition of these dynamic pitfalls can reduce them to straightforward engineering problems. Also there were interdisciplinary interactions and Space Station application oriented issues identified which necessitate thorough system level and integration studies (such as integration of thermal control). As with the other working groups, no special benefits could be identified for flight testing this technology at this time as related to the dynamics and controls discipline. It is virtually mandatory that even a flight system be testable in a lg environment. One issue which is recommended for early resolution is that of laboratory verification of energy recovery efficiency.

A sample of the working group opinions on some of the critical issues is indicated in Figure 2. In the area of magnetic suspension control laws, the current techniques are determined to be adequate and can result in the design of a system which is controllable. Available evidence from simulations indicates that the issues associated with momentum and energy management can be handled. Questions to be answered in that area will be addressed shortly. The important issue of fault isolation and robustness must be examined in the course of a thorough systems level engineering study in which an actual fault isolation approach is defined and embodied during the early phases of the system design. Suitable failure detection, isolation, and correction policies must be devised and must encompass potentially unstable failures. It is evident that this is one of the areas in need of a strong systems level design study to support and

complement the component level design efforts. None of these problems were felt to present insurmountable challenges to the designer. It was the consensus of the group that a strong dynamic-modeling, analysis, and simulation effort during the early design phases is the key to avoiding the potential pitfalls in this class of system.

An opinion poll of the working group regarding the need to develop energy storage wheel (ESW) technology and whether attitude control should be integrated with it for the Space Station application is shown at the bottom of Figure 2. The results reflect a strong affirmative consensus on both issues. Regarding the issues of "ball bearings versus magnetic bearings", and "steel versus composite rotor materials", there was considerable diversity of opinion and no consensus was reached.

In order to focus more clearly on the dynamics and control issues, the next two sections have been organized in terms of the system and component level design issues that directly influence them. In this class of equipment, it is imperative that the various design parameters are selected to insure reasonable stability and control.

## 2. System Level Design Issues

Additional issues which the working group deemed to be important in their potential influence on dynamics and control include (Figure 3)

- 1) To what extent should the attitude control function be integrated with the energy storage function?
- 2) How should the system be configured for simultaneous energy and momentum management?
- 3) What are the key physical design parameters requiring system level trades?

With respect to the first item, the question of torque dynamic range must be addressed. The large torques associated with energy management must be compensated by the momentum management system with sufficient precision that relatively small, noise-free attitude control torques can be provided. Also, life-cycle cost, weight, volume, complexity, and technology readiness issues must be addressed.

The impact of energy and momentum management considerations in the definition of the system configuration must be examined to insure that such issues as safety, reliability needs, and fault detection, isolation, and correction are entertained early in the design phase. Once the system issues have been addressed and the operational requirements defined, the storage unit specifications can then be generated. Several trade-offs must be performed to answer the questions of the number of units, their configuration and mounting arrangement, as well as some implementation characteristics such as rotor material and suspension approach for this rotor. Other significant issues are how to maintain thermal control of the ESW rotor and stator, and the compatibility of this approach with the Space Station thermal control system.

## 3. Component Control System Design Issues

Having addressed the system level considerations, we can now focus on the issues associated with the control of an individual energy storage wheel component (Figure 4).

For example, wheel speed control aspects such as resolution, overspeed prevention, and anomaly detection must be examined. The regulation and distribution of the generated power must be specified. If magnetic suspension of the rotor is utilized, then the magnetic actuator control approach for that system must be selected from a variety of candidates such as all-electromagnetic or permanent magnet flux-bias concepts. In addition the impact of that suspension approach and its control scheme on the structural dynamics of the storage unit and the overall system must be evaluated. Magnetic suspension systems also require special provisions during spacecraft launch, and in case of electronic failure, backup bearings. The technique selected for the control of the gimbal(s) will have a direct impact on the controller bandwidth. In addition, limited gimbal travel to simplify power transfer across rotating interfaces will have to be traded off against additional software costs and complexity. A desirable feature, and probably a required one, is the need for this system to be testable in a lg environment. Of course, the system must be designed for long-term operational life, but if failures do occur, then techniques to accommodate such events must be provided in the system design.

An issue of prime importance in any program of this nature is "what is the next major thrust?" This gives rise to the classical engineering compromise (Figure 5): "What level of technology should be pursued versus how long should this program take and how much should it cost?"

#### 4. Major Steps in the Technology Development

Included in this report is a 10-year schedule starting in 1984 and ending in 1994 (Figure 6). The first launch date is shown to be in January 1994. As can be noted from this schedule, the first task is to upgrade the existing IPACS hardware to permit the early demonstration of the energy recovery efficiency of this concept. The system engineering study, previously mentioned, will entertain all the interacting design issues to arrive at an "optimized" system design. Advanced component development is pursued either in an integrated form, or as shown here, in a parallel fashion, in which the rotor and suspension system definitions are conducted simultaneously with the motor/generator and electronics evolutions. Early integrated system testing is a very crucial step in this program, regardless of the development scenario selected for the components. It was felt by the panel membership that this kind of scheduling can result in a technology readiness date of 1987, which is compatible with the Space Station mission. The development schedule for the flight hardware is also depicted here to show that it is possible to overlap these tasks successfully and to indicate that if this kind of success-oriented program can be maintained, sufficient time exists for the Space Station system evolution.

TABLE 1  
DYNAMICS AND CONTROLS WORKING GROUP  
PANEL MEMBERSHIP

<u>NAME</u>	<u>ORGANIZATION</u>	<u>PHONE</u>
H. F. Kennel	NASA-MSFC	(205)453-4718
D. D. Nixon	NASA-MSFC	(205)453-2714
J. L. Williams	NASA-LaRC	(804)865-2486
H. R. Whitman	C.S. Draper Laboratory	(617)258-3374
J. Rinderle	Carnegie-Mellon U.	(412)578-3677
F. R. Penovich	NASA-KSC	(305)867-2036
R. Benhabib	TRW	(213)536-1891
G. Stocking	Sperry-Space Division	(602)869-2033
R. E. Oglevie	Rockwell International	(213)922-0248
H. Hoffman	NASA-GSFC	(301)344-8496
N. J. Groom	NASA-LaRC	(804)865-3350
P. D. Nicaise	NASA-MSFC	(205)453-3668

### SUMMARY

- CONTROLS AND DYNAMICS TECHNOLOGY IS ADEQUATE FOR THE  
DEVELOPMENT OF ESW TECHNOLOGY
  - . MAGNETIC SUSPENSION CONTROL LAWS
  - . MOMENTUM AND ENERGY MANAGEMENT
  - . CONTROL BANDWIDTH CONSIDERATIONS, ETC.
- MANY ISSUES DEFINED THAT NEED TO BE INCLUDED IN SYSTEMS LEVEL  
STUDY DURING TECHNOLOGY DEVELOPMENT PHASE
- FLIGHT TESTING NEED?  
NO SPECIAL BENEFITS DEFINED
- EARLY LABORATORY VERIFICATION OF ENERGY RECOVERY EFFICIENCY  
(END-TO-END) IS NEEDED

Figure 1

WORKING GROUP OPINIONS ON EXAMPLE ISSUES

- SUSPENSION SYSTEM CONTROL LAWS?

CURRENT TECHNIQUES ADEQUATE, DESIGN TO BE CONTROLLABLE

- MOMENTUM AND ENERGY MANAGEMENT?

NO PROBLEMS

- FAULT ISOLATION/ROBUSTNESS?

IMPORTANT, BEST APPROACH SHOULD BE DEFINED IN "SYSTEM-LEVEL"  
DESIGN STUDY

- CONTINGENCY CRITERIA AFTER UNIT FAILURE?

NEED TO DO DYNAMICS AND CONTROL ANALYSIS OF POTENTIAL FAILURE  
MODES, OTHERWISE SAME ANSWER AS ABOVE

- MODELING?

ENERGY STORAGE UNIT DYNAMICS IMPORTANT, SAME AS ABOVE

- WORKING GROUP OPINIONS BY VOTE:

. SHOULD E.S.W. TECHNOLOGY DEVELOPMENT BE PURSUED?

9 - YES; 0 - NO; 2 - NO OPINION

. INTEGRATE ATTITUDE CONTROL WITH ENERGY STORAGE?

7 - YES; 0 - NO; 4 - NO OPINION

Figure 2

SYSTEM LEVEL DESIGN ISSUES  
(OR "HOW TO DESIGN FOR CONTROLLABILITY")

- EXTENT OF INTEGRATING ACS/EPS?
  - . TORQUE DYNAMIC RANGE COMPATIBILITY
  - . COST, WEIGHT, AND VOLUME SAVINGS?
  - . COMPLEXITY AND READINESS
- HOW TO CONFIGURE FOR ENERGY AND MOMENTUM MANAGEMENT?
  - . SPATIAL DISTRIBUTION, CENTRALIZED OR NOT?  
(HOW MANY AND WHERE?)
  - . HOW ACCOMMODATE SAFETY? RELIABILITY NEEDS; FAULT DETECTION,  
ISOLATION, AND CORRECTION? CONTAINMENT VS. OTHERS?
  - . MODULARITY, GROWTH PROVISIONS, TECHNOLOGY UPGRADING
  - . ACCOMMODATION OF STRUCTURAL COMPLIANCE, INTERNAL AND EXTERNAL  
TO UNITS
- PHYSICAL CONFIGURATION
  - . NUMBER OF UNITS AND GIMBALS (0, 1, OR 2)?
  - . MOUNTING ARRANGEMENT(S)?
  - . BALL BEARING VS. MAGNETIC?
  - . ROTOR MATERIAL- STEEL VS. COMPOSITE X, Y, OR Z?
  - . THERMAL CONTROL

Figure 3

## COMPONENT CONTROL SYSTEM DESIGN ISSUES

- WHEEL SPEED CONTROL
  - . RESOLUTION
  - . OVERSPEED CONTROL
  - . ANOMALY DETECTION - SENSORS AND SOFTWARE
- POWER CONTROL
  - . REGULATION
  - . DISTRIBUTION
- MAGNETIC SUSPENSION CONTROL
  - . ELECTROMAGNETIC
  - . PERMANENT MAGNET
  - . STRUCTURAL DYNAMICS
  - . GRACEFUL FAILURE DETECTION
  - . TOUCHDOWN BEARINGS
  - . LAUNCH PROVISIONS
- GIMBAL CONTROL
  - . PRECESSION CONTROL
  - . AUXILIARY CONTROL MODES (RUN UP)
  - . NONLINEARITIES (LIMITED GIMBAL FREEDOM)
- 1g DEMONSTRATION OF DUAL FUNCTION
- DESIGN FOR LONG LIFE
- FAILURE ACCOMMODATION TECHNIQUES

Figure 4



**"THE CLASSIC ENGINEERING COMPROMISE"**

**TECHNOLOGY LEVEL**

**VS**

**COST AND SCHEDULE**

**Figure 5**

# MAJOR STEPS IN THE TECHNOLOGY DEVELOPMENT

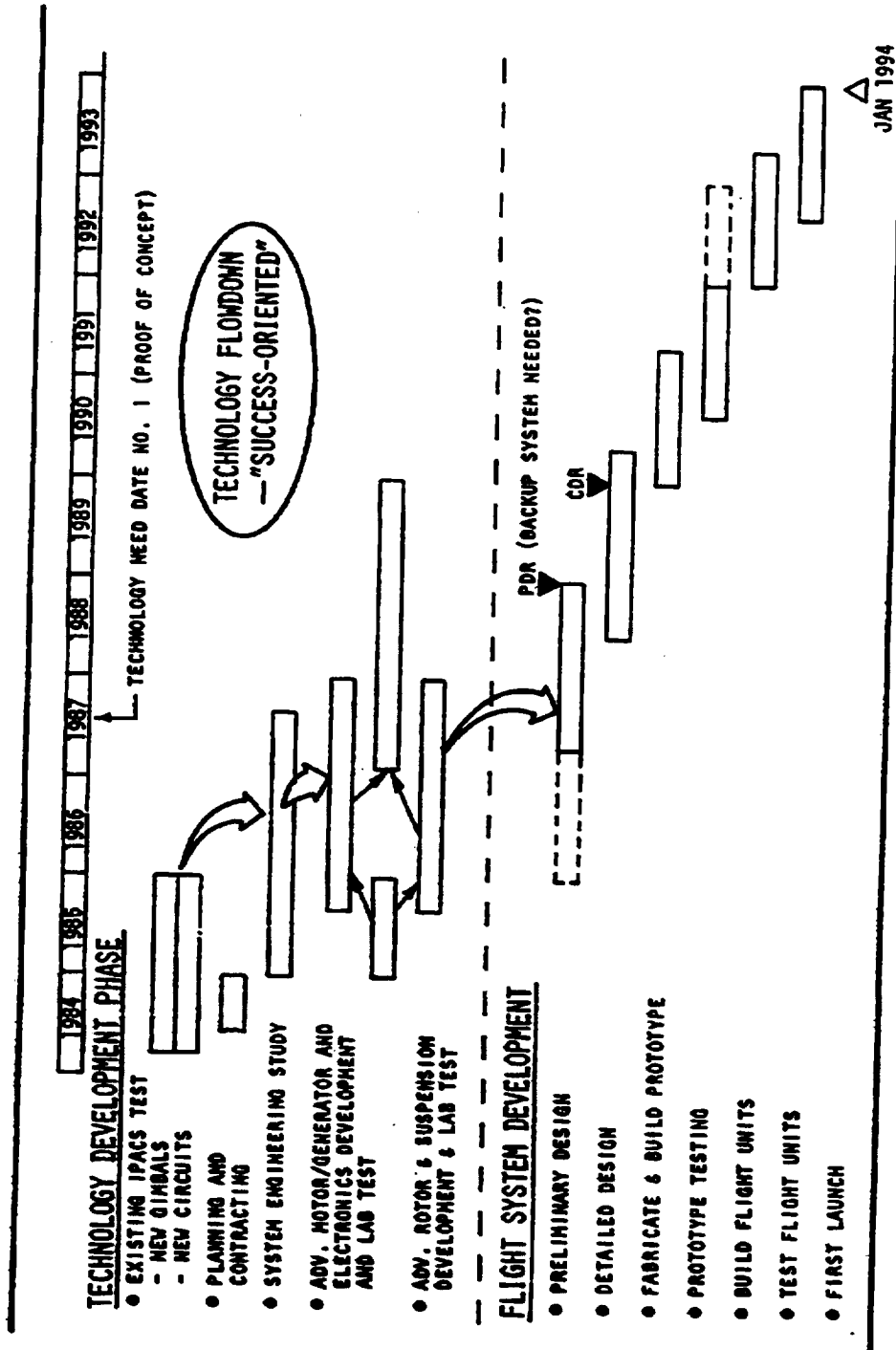


Figure 6